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AUTHOR Kelley, D. Lynn; And Others
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ABSTRACT

The Type I error and power properties of the 2x2x2 analysis of variance (ANOVA) and tests developed by McSweeney (1967), Bradley (1979), Harwell-Serlin (1989; Harwell, 1991), and Blair-Sawilowsky (1990) were compared using Monte Carlo methods. The ANOVA was superior under the Gaussian and uniform distributions. The Blair-Sawilowsky test was superior under the exponential and t-test distributions. The Bradley test was robust. The McSweeney test was conservative under several conditions. The Harwell-Serlin test was both conservative and anti-conservative under various conditions. Seven tables and six figures are included. (Contains 13 references.) (Author/SLD)

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COMPARISON OF ANOVA, MCSWEENEY, BRADLEY, HARWELL-SERLIN, AND BLAIR-SAWILOWSKY TESTS IN THE BALANCED 2x2x2 LAYOUT

D. Lynn Kelley, Shlomo S. Sawilowsky, and R.C. Blair

D. Lynn Kelley, Madonna University, 36600 Schoolcraft, Livonia, MI 48150

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D. Lynn Kelley, Shlomo S. Sawilowsky, and R. C. Blair
D. Lynn Kelley, Madonna University, 36600 Schoolcraft, Livonia, MI 48150

The Type I error and power properties of the 2x2x2 ANOVA and tests developed by McSweeney (1967), Bradley (1979), Harwell-Serlin (1989; Harwell, 1991), and Blair-Sawilowsky (1990; Sawilowsky, 1990) were compared using Monte Carlo methods. The ANOVA was superior under the Gaussian and uniform distributions. The Blair-Sawilowsky test was superior under the exponential and t (df=3) distributions. The Bradley test was robust. The McSweeney test was conservative under several conditions. The Harwell-Serlin test was both conservative and anti-conservative under various conditions.

Over the past 25 years, many new tests for interactions have been developed as alternatives to the parametric Analysis of Variance F test. Although Glass, Peckham, and Sanders (1972) provided simulation evidence of the robustness of the F test with respect to Type I and II errors, Scheffe (1959) noted that this should not be confused with its comparative power with alternative statistics. Sawilowsky (1990) reviewed ten nonparametric tests for interaction. Among these, four statistics were chosen for the current study because they were noted by Sawilowsky to be relatively easy to compute, either by hand or within the framework of current computer statistics packages.

Computation of Statistics

The McSweeney test is conducted by aligning scores and then ranking the resultant values. The test statistic is the sum of squares for the effect of interest divided by the sum of squares total, referenced to a Chi-Square distribution.

The Harwell-Serlin test is based on the Puri and Sen L test (Puri & Sen, 1969; 1971). Harwell and Serlin adapted Puri and Sen's L statistic in trace criterion form, permitting it to be calculated easily by hand or with a computer statistics package. The test is carried out in an identical fashion to the McSweeney test, except no alignment is performed prior to ranking. The test statistic is referenced to a Chi-Square distribution with modified degrees of freedom.

Bradley (1979) explained his procedure as follows,

> First, the data are collapsed over all variables except replicates and those variables whose interaction is to be tested. Then, by a series of subtractions, the resulting data table is reduced to one in which all lower-order effects have been eliminated and which now contains only as many cells as there are degrees of freedom for the interaction of interest. At this point, a test for main effects applied to the cells of the reduced table is equivalent to a test for interaction in the original data base. So the final step is to apply the appropriate nonparametric test for main effects to the data in the reduced table. (p. 177)

In the context of the 2x2x2 layout the appropriate main effects test to be used for testing the higher order interaction under Bradley's procedure is the Wilcoxon signed-rank test.

The Blair-Sawilowsky (1990; Sawilowsky, 1990) test is based on the rank transform. First, nuisance parameters (i.e., the main effects as represented by the column and row means) are subtracted from the scores, then the resultant values are ranked. The usual Analysis of Variance is calculated on the adjusted ranks. The test statistic is then referenced to the F distribution. This test

is similar to a more computationaly complete procedure independently developed by Fawcett and Salter (1984), who also subtract the grand mean.

Study Conditions

A FORTRAN 77 program was written for the Hewlett-Packard 9000/735 Unix workstation, and IMSL (1988) subroutines were accessed. Both theoretical distributions and real data sets were examined. The theoretical distributions were the Gaussian, uniform, t (df=3), and exponential. The real data sets used were the multi-modal lumpy (based on achievement scores) and the discrete mass at zero with gap (based on psychometric scores), which were chosen from Micceri (1989). Samples sizes were n=7, 21 and 35. Effect Sizes (ES) were c=.2 - 1.2 (.2); and nominal alpha was set to .050 and .010.

The data generation model used random values sampled from the theoretical distributions, and sampling with replacement from the data sets. The model was in the form of the general linear model as follows:

$$x_{ijkl} = \mu + A_i + B_j + C_k + (ab)_{ij} + (ac)_{ik} + (bc)_{jk} + (abc)_{ijk} + e_{ijkl}$$

$i = 1, 2$
$j = 1, 2$
$k = 1, 2$
$l = 7, 21, \text{or } 35$

The treatment conditions were (a) all effects were null except for the A main effect which was nonnull; (b) all effects were null except for the A and B main effects; (c) all effects were null except for the A, B and C main effects; (d) all effects were null except for the A, B and C main effects and the (bc) interaction; (e) all effects were null except for the A, B, and C main effects and the (bc) and (ac) interactions; (f) all effects were null except for the A, B and C main effects and the (bc), (ac), and (ab) interactions; (g) the A, B and C main effects and the (bc), (ac), (ab) and (abc) interactions were nonnull.

The (ab) interactions were modeled by making $(ab)_{11} = (ab)_{22} = c$, during which time $(ab)_{21} = (ab)_{12} = -c$, where c assumed the values 0.20σ, 0.40σ, 0.60σ, 0.80σ, 1.00σ, and 1.20. The (ac) and (bc) interactions were modeled in a corresponding way. The (abc) interaction was modeled by making $(abc)_{111} = (abc)_{221} = (abc)_{212} = (abc)_{122} = c$, and $(abc)_{211} = (abc)_{121} = (abc)_{112} = (abc)_{222} = -c$, where c assumed the values 0.20σ, 0.40σ, 0.60σ, 0.80σ, 1.00σ, and 1.20σ.

To ensure the veracity of the FORTRAN code, the Type I error rates were checked for the statistics under the truth of the null hypothesis (Table 1). The actual alpha levels were within sampling error of .050 and .010 for all statistics studied.

Type I Error Results

With the exception of the Harwell-Serlin and McSweeney statistics, all tests maintained appropriate Type I error rates for null effects in treatment conditions (a)-(f) mentioned above (Tables 2-7). In testing for main effects and lower order interactions, the Harwell-Serlin statistic became increasingly conservative and then anti-conservative as the number of nonnull effects increased in the model and ES became large, particularly for the t (df=3) and exponential distributions. For example, under the exponential distribution, n=7, alpha=.050, and ES=.8, the average Type I error rates for null effects in treatment conditions (a)-(f) were .026, .016, .011, .011, .024, and .147. The McSweeney test became conservative as the number of nonnull effects increased and the ES became large.

Power Results

Under the Gaussian and uniform distributions, the ANOVA was the most powerful test (Figures 1 & 2). The Blair-Sawilowsky test was slightly less powerful than ANOVA under these two distributions. The McSweeney and Bradley tests were less powerful than Blair-Sawilowsky. The Harwell-Serlin test was the least powerful test. However, for the exponential and t (df=3) distributions, the Blair-Sawilowsky test was the most powerful test (Figures 3 & 4). The ANOVA was the most powerful test under the multi-modal lumpy data set (Figure 5), and the Blair-Sawilowsky was the most powerful test under the discrete mass at zero data set (Figure 6).

Recommendations

On the basis of its robustness to departures from normality, its superior power properties, and its simplicity to calculate, the Blair-Sawilowsky test appears to be the best choice for testing interactions in the balanced 2x2x2 layout when the underlying distribution is nonnormal or unknown. If the data are perchance normal, very little power is lost in comparison to the ANOVA. For the more likely situation of nonnormality, considerable power will be gained by using the Blair-Sawilowsky test over ANOVA, Bradley, Harwell-Serlin and McSweeney tests.

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Table 1
Type I error rates of the ANOVA F, Bradley and Harwell-Serlin tests when all effects are null and sampling is from various population shapes.

Population	Statistic	Sample size 7	Sample size 35
Gaussian	F	0.050	0.050
	B	0.046	0.050
	H-S	0.050	0.050
Uniform	F	0.051	0.051
	B	0.048	0.049
	H-S	0.050	0.050
t (df = 3)	F	0.046	0.049
	B	0.046	0.050
	H-S	0.049	0.051
Exponential	F	0.047	0.049
	B	0.047	0.050
	H-S	0.051	0.050
Multi-modal lumpy	F	0.050	0.049
	B	0.044	0.049
	H-S	0.050	0.049
Discrete mass at zero	F	0.049	0.050
	B	0.046	0.050
	H-S	0.050	0.050

Table 2
Type I error rates and power levels of the ANOVA F, Bradley, Harwell-Serlin, Blair-Sawilowsky and McSweeney tests when sampling is from the Gaussian distribution and n=7.

			Number of nonnull effects						
c	Stat	Outcome	1	2	3	4	5	6	7
0.20	F	α	0.052	0.050	0.050	0.050	0.047	0.052	n/a
		1-ß	0.108	0.113	0.114	0.115	0.113	0.113	0.115
	B	α	0.048	0.045	0.048	0.046	0.047	0.047	n/a
		1-ß	n/a	n/a	n/a	0.089	0.085	0.085	0.087
	H-S	α	0.050	0.048	0.048	0.046	0.044	0.046	n/a
		1-ß	0.106	0.108	0.107	0.107	0.102	0.100	0.098
	B-S	α	0.052	0.050	0.051	0.051	0.049	0.053	n/a
		1-ß	0.108	0.110	0.112	0.114	0.111	0.113	0.112
	M	α	0.050	0.052	0.053	0.044	0.042	0.044	n/a
		1-ß	0.106	0.113	0.118	0.104	0.099	0.098	0.102
0.80	F	α	0.049	0.048	0.049	0.049	0.049	0.049	n/a
		1-ß	0.833	0.834	0.833	0.834	0.833	0.834	0.835
	B	α	0.046	0.048	0.046	0.044	0.045	0.045	n/a
		1-ß	n/a	n/a	n/a	0.665	0.665	0.665	0.671
	H-S	α	0.034	0.024	0.017	0.013	0.015	0.027	n/a
		1-ß	0.815	0.777	0.719	0.666	0.567	0.451	0.317
	B-S	α	0.049	0.050	0.050	0.049	0.049	0.049	n/a
		1-ß	0.815	0.812	0.815	0.814	0.816	0.813	0.809
	M	α	0.034	0.035	0.037	0.030	0.023	0.015	n/a
		1-ß	0.815	0.817	0.824	0.799	0.757	0.706	0.707

α=.05

Table 3
Type I error rates and power levels of the ANOVA F, Bradley, Harwell-Serlin, Blair-Sawilowsky and McSweeney tests when sampling is from the uniform distribution and n=7.

			Number of nonnull effects						
c	Stat	Outcome	1	2	3	4	5	6	7
0.20	F	α	0.051	0.050	0.051	0.050	0.053	0.050	n/a
		1-ß	0.111	0.113	0.108	0.113	0.113	0.111	0.113
	B	α	0.046	0.046	0.047	0.045	0.047	0.046	n/a
		1-ß	n/a	n/a	n/a	0.085	0.084	0.084	0.086
	H-S	α	0.049	0.047	0.047	0.045	0.047	0.045	n/a
		1-ß	0.108	0.108	0.099	0.102	0.100	0.095	0.094
	B-S	α	0.051	0.050	0.051	0.050	0.052	0.051	n/a
		1-ß	0.108	0.112	0.105	0.107	0.109	0.106	0.108
	M	α	0.049	0.051	0.053	0.043	0.045	0.042	n/a
		1-ß	0.108	0.115	0.110	0.098	0.095	0.093	0.098
0.80	F	α	0.052	0.050	0.051	0.051	0.050	0.051	n/a
		1-ß	0.832	0.888	0.833	0.834	0.835	0.836	0.836
	B	α	0.047	0.046	0.049	0.046	0.049	0.047	n/a
		1-ß	n/a	n/a	n/a	0.658	0.661	0.662	0.662
	H-S	α	0.037	0.026	0.019	0.016	0.013	0.019	n/a
		1-ß	0.777	0.730	0.677	0.631	0.548	0.448	0.329
	B-S	α	0.051	0.050	0.051	0.051	0.050	0.051	n/a
		1-ß	0.777	0.785	0.777	0.772	0.774	0.773	0.769
	M	α	0.031	0.038	0.039	0.033	0.024	0.017	n/a
		1-ß	0.777	0.790	0.787	0.755	0.715	0.664	0.667

α=.05

Table 4
Type I error rates and power levels of the ANOVA F, Bradley, Harwell-Serlin and Blair-Sawilowsky tests when sampling is from the t distribution with 3 degrees of freedom and n=7.

			Number of nonnull effects						
c	Stat	Outcome	1	2	3	4	5	6	7
0.20	F	α	0.046	0.044	0.046	0.046	0.048	0.046	n/a
		1-ß	0.133	0.133	0.133	0.136	0.134	0.136	0.135
	B	α	0.047	0.045	0.049	0.048	0.046	0.050	n/a
		1-ß	n/a	n/a	n/a	0.105	0.106	0.109	0.108
	H-S	α	0.047	0.044	0.043	0.042	0.041	0.038	n/a
		1-ß	0.172	0.169	0.162	0.159	0.149	0.143	0.135
	B-S	α	0.055	0.049	0.050	0.050	0.052	0.051	n/a
		1-ß	0.174	0.163	0.173	0.170	0.169	0.176	0.172
0.80	F	α	0.045	0.046	0.047	0.047	0.044	0.048	n/a
		1-ß	0.870	0.870	0.871	0.870	0.871	0.869	0.870
	B	α	0.047	0.047	0.047	0.046	0.047	0.044	n/a
		1-ß	n/a	n/a	n/a	0.749	0.754	0.751	0.753
	H-S	α	0.025	0.013	0.008	0.009	0.021	0.131	n/a
		1-ß	0.972	0.937	0.890	0.819	0.690	0.517	0.316
	B-S	α	0.050	0.050	0.050	0.050	0.048	0.052	n/a
		1-ß	0.972	0.970	0.969	0.967	0.959	0.929	0.943

α=.05

Table 5
Type I error rates and power levels of the ANOVA F, Bradley, Harwell-Serlin and Blair-Sawilowsky tests when sampling is from the exponential distribution and n=7.

			Number of nonnull effects						
c	Stat	Outcome	1	2	3	4	5	6	7
0.20	F	α	0.047	0.047	0.047	0.048	0.048	0.049	n/a
		1-ß	0.119	0.118	0.120	0.121	0.122	0.120	0.122
	B	α	0.046	0.047	0.044	0.045	0.049	0.047	n/a
		1-ß	n/a	n/a	n/a	0.095	0.095	0.094	0.095
	H-S	α	0.046	0.045	0.042	0.042	0.040	0.048	n/a
		1-ß	0.124	0.196	0.183	0.171	0.159	0.146	0.130
	B-S	α	0.049	0.051	0.052	0.052	0.051	0.052	n/a
		1-ß	0.216	0.200	0.188	0.201	0.198	0.192	0.165
0.80	F	α	0.048	0.049	0.048	0.049	0.047	0.047	n/a
		1-ß	0.831	0.836	0.834	0.835	0.834	0.835	0.834
	B	α	0.049	0.047	0.048	0.048	0.045	0.043	n/a
		1-ß	n/a	n/a	n/a	0.694	0.688	0.690	0.687
	H-S	α	0.026	0.016	0.011	0.011	0.024	0.147	n/a
		1-ß	0.959	0.914	0.855	0.779	0.650	0.495	0.308
	B-S	α	0.051	0.052	0.052	0.052	0.047	0.047	n/a
		1-ß	0.960	0.964	0.956	0.960	0.943	0.899	0.913

α=.05

Table 6
Type I error rates and power levels of the ANOVA F, Bradley, Harwell-Serlin, Blair-Sawilowsky and McSweeney tests when sampling is from the multi-modal lumpy data set and n=7.

			Number of nonnull effects						
c	Stat	Outcome	1	2	3	4	5	6	7
0.20	F	α	0.050	0.050	0.050	0.051	0.050	0.051	n/a
		1-ß	0.109	0.111	0.114	0.111	0.112	0.111	0.112
	B	α	0.044	0.046	0.046	0.046	0.046	0.048	n/a
		1-ß	n/a	n/a	n/a	0.088	0.088	0.084	0.087
	H-S	α	0.048	0.047	0.046	0.045	0.044	0.044	n/a
		1-ß	0.132	0.120	0.117	0.111	0.110	0.103	0.096
	B-S	α	0.050	0.050	0.051	0.050	0.050	0.051	n/a
		1-ß	0.132	0.126	0.124	0.119	0.119	0.118	0.115
	M	α	0.050	0.050	0.053	0.043	0.042	0.042	n/a
		1-ß	0.132	0.127	0.132	0.107	0.106	0.103	0.105
0.80	F	α	0.049	0.051	0.052	0.050	0.050	0.049	n/a
		1-ß	0.836	0.835	0.836	0.835	0.836	0.837	0.835
	B	α	0.043	0.045	0.047	0.047	0.047	0.042	n/a
		1-ß	n/a	n/a	n/a	0.665	0.670	0.670	0.668
	H-S	α	0.034	0.026	0.019	0.015	0.014	0.025	n/a
		1-ß	0.813	0.744	0.694	0.641	0.556	0.454	0.329
	B-S	α	0.049	0.051	0.040	0.049	0.050	0.049	n/a
		1-ß	0.813	0.809	0.819	0.805	0.790	0.758	0.772
	M	α	0.034	0.037	0.040	0.031	0.024	0.017	n/a
		1-ß	0.813	0.813	0.819	0.791	0.728	0.647	0.722

α=.05

Table 7
Type I error rates and power levels of the ANOVA F, Bradley, Harwell-Serlin, Blair-Sawilowsky and McSweeney tests when sampling is from the discrete mass at zero data set and n=7.

			Number of nonnull effects						
c	Stat	Outcome	1	2	3	4	5	6	7
0.20	F	α	0.049	0.051	0.048	0.050	0.049	0.052	n/a
		1-ß	0.116	0.117	0.117	0.117	0.117	0.115	0.115
	B	α	0.046	0.046	0.045	0.044	0.046	0.045	n/a
		1-ß	n/a	n/a	n/a	0.088	0.088	0.089	0.088
	H-S	α	0.044	0.043	0.040	0.040	0.042	0.056	n/a
		1-ß	0.319	0.252	0.217	0.192	0.167	0.151	0.120
	B-S	α	0.050	0.051	0.051	0.053	0.052	0.057	n/a
		1-ß	0.325	0.245	0.211	0.158	0.161	0.165	0.165
	M	α	0.045	0.047	0.050	0.040	0.039	0.042	n/a
		1-ß	0.319	0.247	0.216	0.138	0.136	0.133	0.141
0.80	F	α	0.050	0.048	0.050	0.050	0.049	0.050	n/a
		1-ß	0.835	0.835	0.829	0.832	0.834	0.832	0.833
	B	α	0.045	0.042	0.048	0.046	0.045	0.044	n/a
		1-ß	n/a	n/a	n/a	0.677	0.679	0.678	0.679
	H-S	α	0.028	0.018	0.014	0.014	0.026	0.106	n/a
		1-ß	0.934	0.873	0.801	0.741	0.607	0.473	0.312
	B-S	α	0.051	0.050	0.052	0.053	0.056	0.061	n/a
		1-ß	0.933	0.934	0.931	0.927	0.904	0.836	0.876
	M	α	0.028	0.029	0.032	0.026	0.019	0.020	n/a
		1-ß	0.934	0.935	0.935	0.916	0.857	0.740	0.789

α=.05

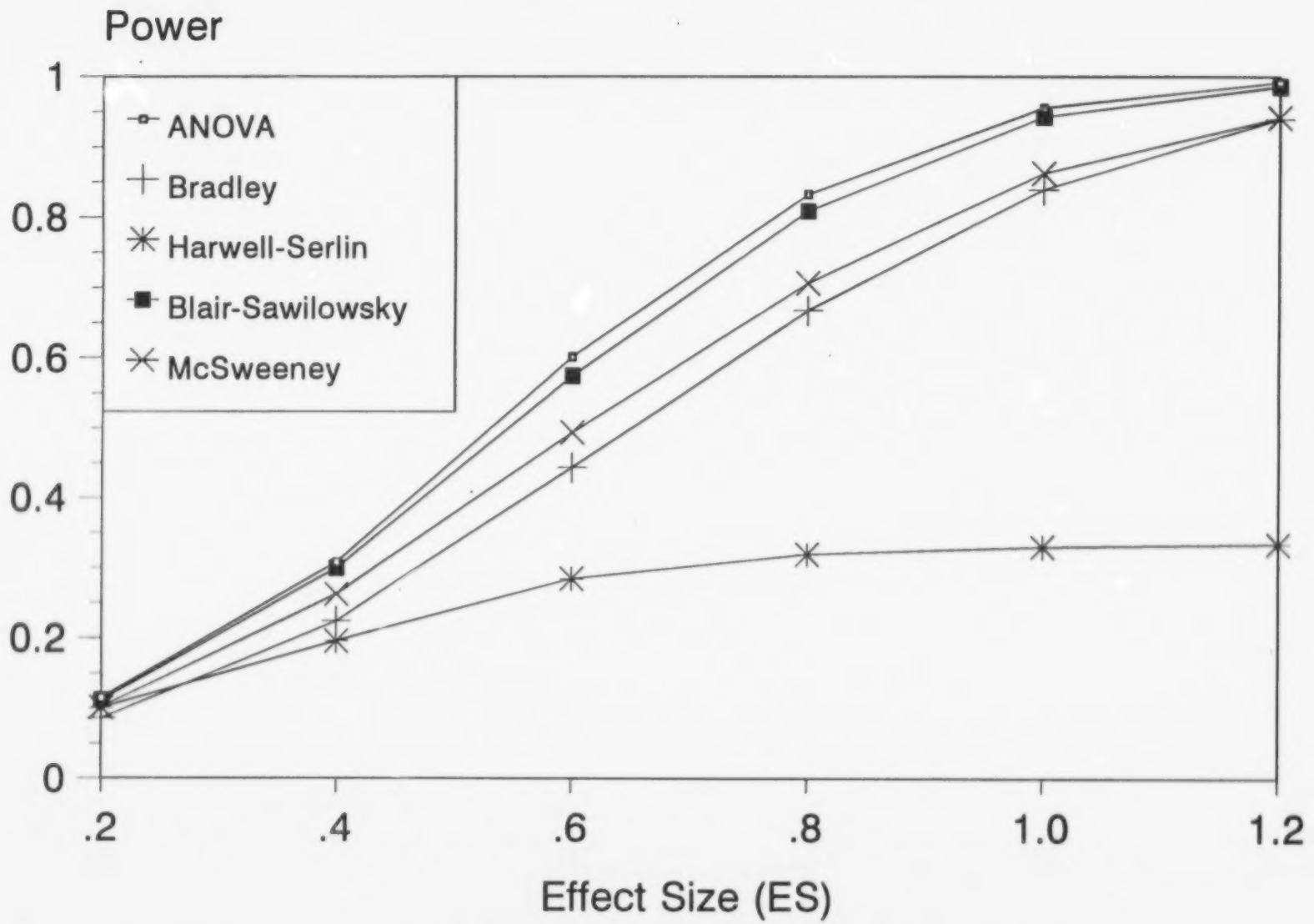

Figure 1. Comparative power of (abc) interaction for the Analysis of Variance (ANOVA), Bradley, Harwell-Serlin, Blair-Sawilowsky and McSweeney tests when sampling is from the Gaussi distribution, alpha=.05 and n=7.

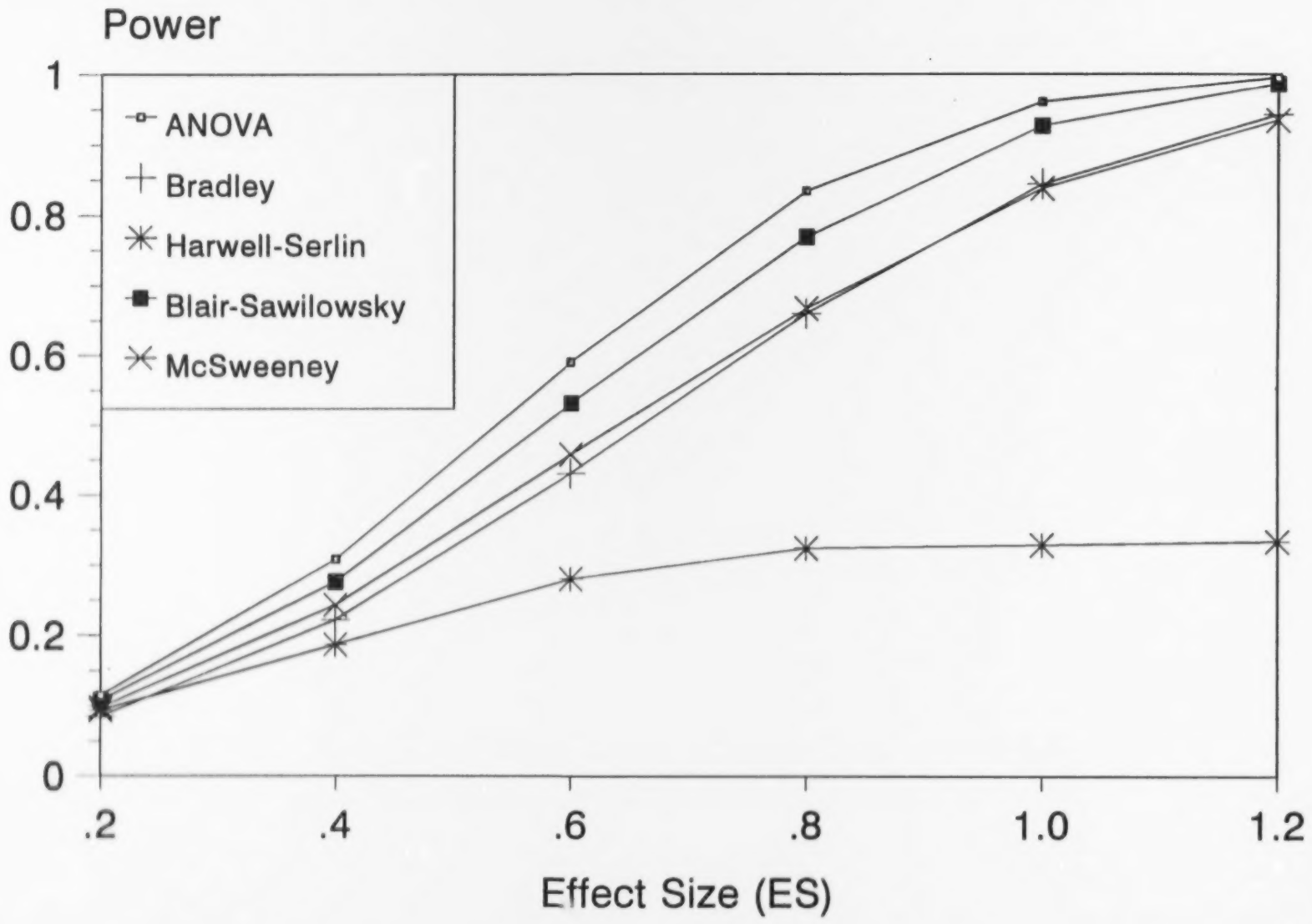

Figure 2. Comparative power of the (abc) interaction for the Analysis of Variance (ANOVA), Bradley, Harwell-Serlin, Blair-Sawilowsky and McSweeney tests when sampling is from the uniform distribution, alpha=.05 and n=7.

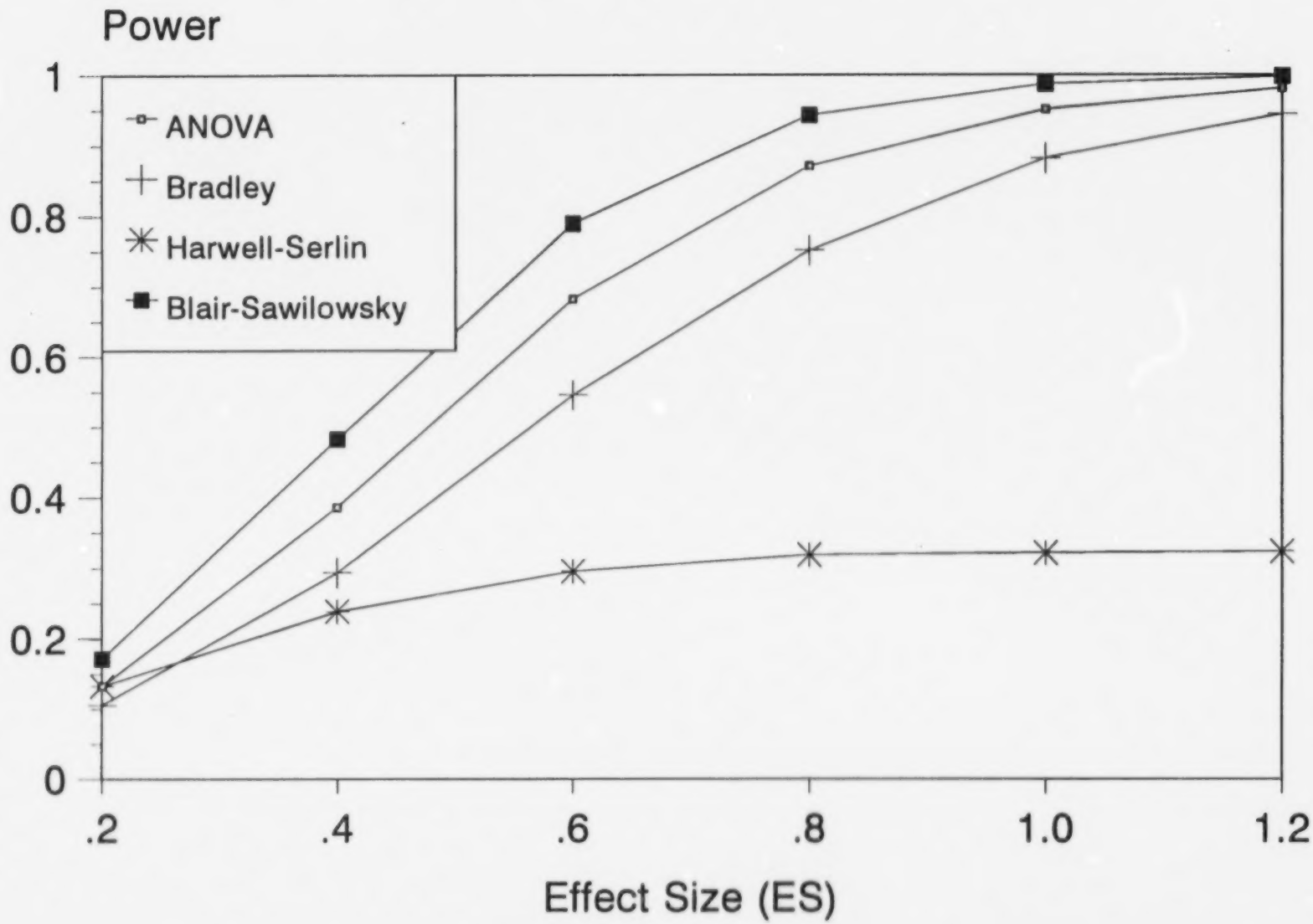

Figure 3. Comparative power of the (abc) interaction for the Analysis of Variance (ANOVA), Bradley, Harwell-Serlin and Blair-Sawilowsky tests when sampling is from the t distribution with three degrees of freedom, alpha=.05 and n=7.

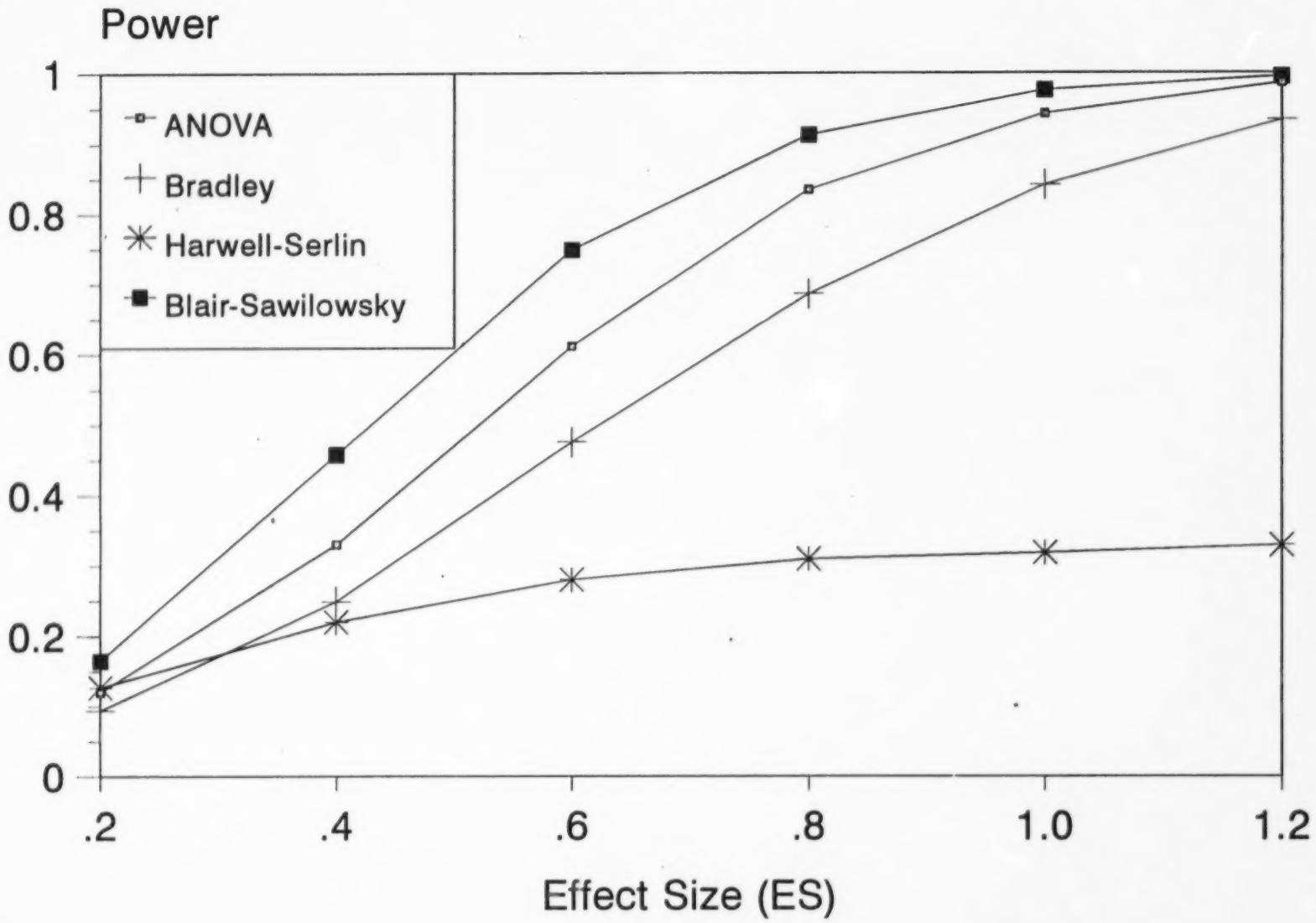

Figure 4. Comparative power of the (abc) interaction for the Analysis of Variance (ANOVA), Bradley, Harwell-Serlin and Blair-Sawilowsky tests when sampling is from the exponential distribution, alpha=.05 and n=7.

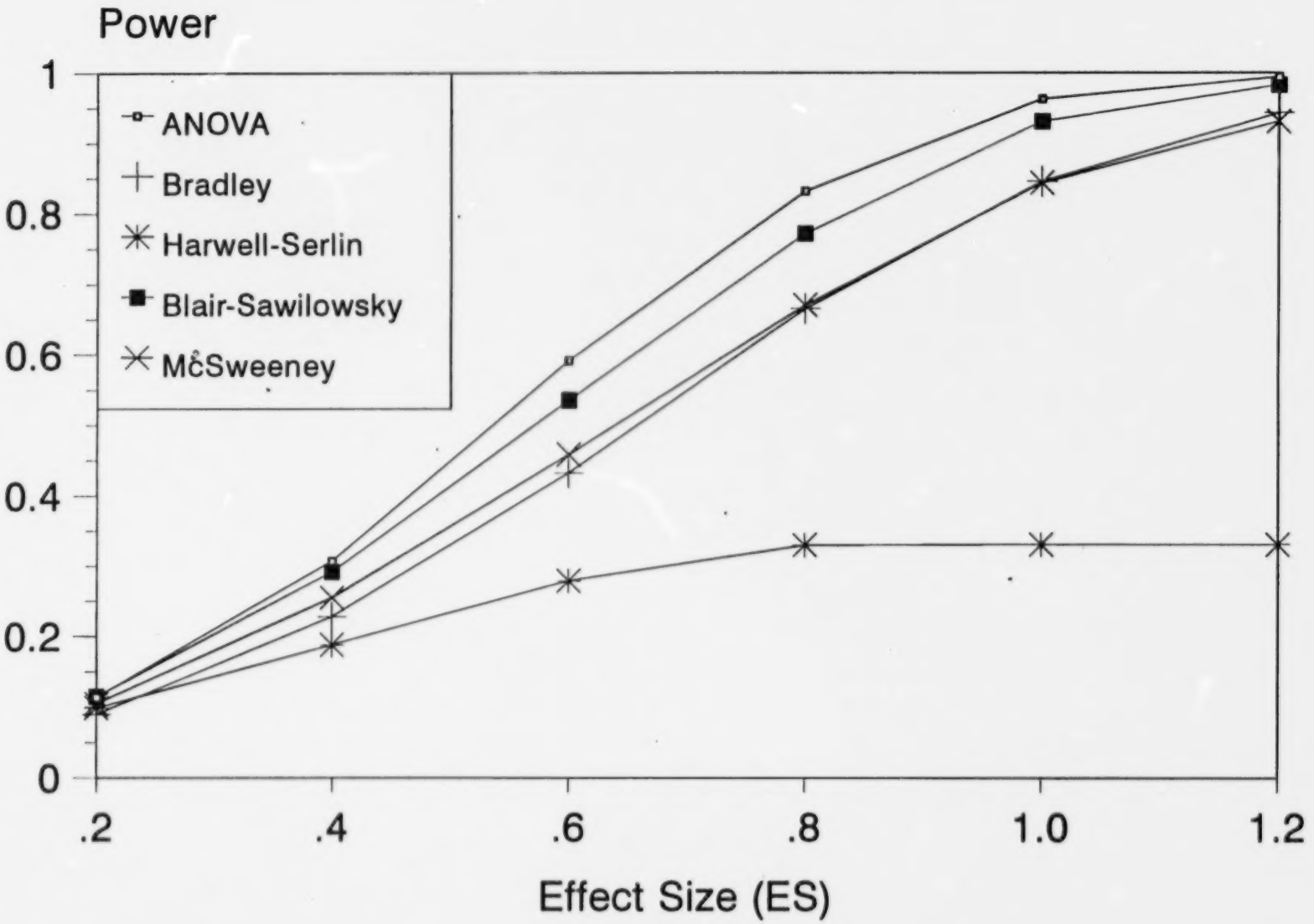

Figure 5. Comparative power of (abc) interaction for the Analysis of Variance (ANOVA), Bradley, Harwell-Serlin, Blair-Sawilowsky and McSweeney tests when sampling is from the multi-modal lumpy data set, alpha=.05 and n=7.

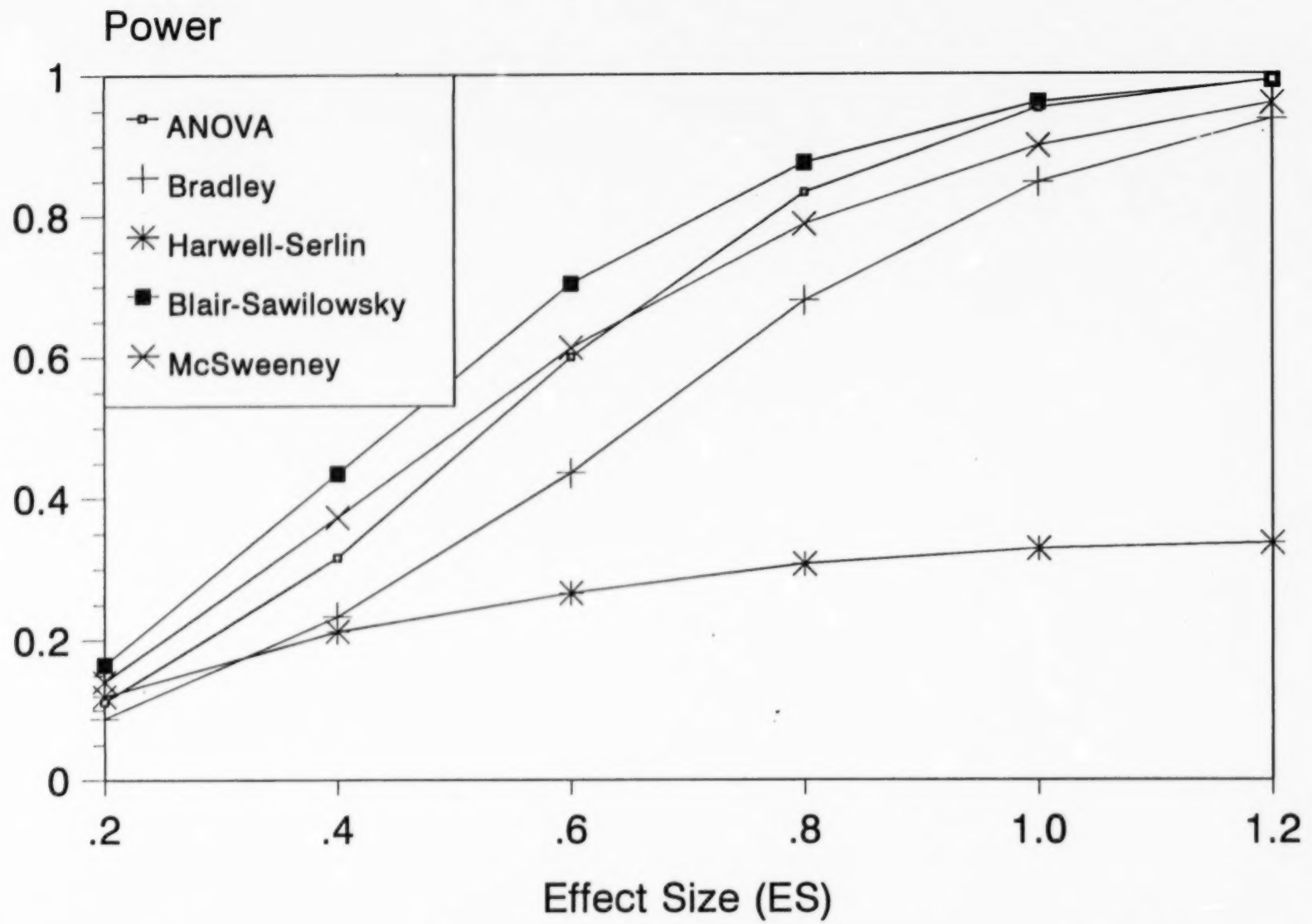

Figure 6. Comparative power of the (abc) interaction effect for the Analysis of Variance (ANOVA), Harwell-Serlin, Blair-Sawilowsky and McSweeney tests when sampling is from the discrete mass at zero data set, alpha=.05 and n=7.